

Ellipsometric investigation of Fe-based amorphous thin films

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FeSiB amorphous thin films deposited onto glass substrate by pulsed laser method are investigated. The used ablation target was made of Fe₇₉Si₉B₁₂ amorphous ribbons. The refractive index, extinction coefficient, magneto-optical constant and coercive force of the deposited films have been determined by means of ellipsometry and magneto-optical ellipsometry. The measurements made at 632.8 nm wavelength give 2.3, 1.75 and 0.0177-0.0663j for n , k and Q , respectively.

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1. Introduction

Ellipsometry is a sensitive optical technique for surface and thin films properties investigation [1]. The refractive index, n , the extinction coefficient, k , and the thickness of a material can be determined by means of ellipsometric measurements.

Surface magnetism is a topic of increasing interest in the study of near surface physical properties of thin films. One of the most frequently used technique for the surface magnetic characterization is based on the magneto-optical Kerr effect (MOKE) [2-9].

The aim of this paper is to determine the refractive index, extinction coefficient and magneto-optical constant, Q , of amorphous FeSiB thin films obtained by pulsed laser deposition.

2. Theory

Ellipsometry measures variations of the polarization state of light reflected from a surface. The experimental data are expressed as $tg\psi$ (relative amplitude ratio) and Δ (relative phase shift) related to the Fresnel reflection complex coefficients r_p and r_s for p and s polarized light (polarized in the incidence plane or perpendicular to it, respectively). The basic ellipsometry equation is [1]:

$$tg\psi e^{j\Delta} = \frac{r_p}{r_s} \quad (1)$$

The n and k values were calculated from the measured Ψ and Δ values, using equation [1]:

$$(n + jk)^2 = \sin^2 \theta \left\{ 1 + \tan^2 \theta \left[\frac{1 - \tan \Psi e^{j\Delta}}{1 + \tan \Psi e^{j\Delta}} \right]^2 \right\} \quad (2)$$

where: θ is the incidence angle.

Magneto-optical Kerr effect consists in the change of polarization/intensity of the incident polarized light when is reflected by the surface of a magnetized medium. The Kerr rotation/ellipticity of the light polarization is proportional to the investigated sample's magnetization. MOKE involves reflection magneto-optical Fresnel matrix with r_{ij} elements (r_{ij} is the ratio of the incident j polarized electric field to the reflected i polarized electric field) [2-5]. For optically thick magnetic films, the multiple reflections could be ignored and, in the case of an incident beam light from a non-magnetic to a magnetic medium, the magneto-optical Fresnel reflection coefficients r_{ij} are [2-5]:

$$r_{pp} = \frac{N_1 \cos \theta_0 - N_0 \cos \theta_1}{N_1 \cos \theta_0 + N_0 \cos \theta_1} - j \frac{2N_0 N_1 \cos \theta_0 \sin \theta_1 m_x Q}{N_1 \cos \theta_0 + N_0 \cos \theta_1} \quad (3)$$

$$r_{sp} = \frac{jN_0 N_1 \cos \theta_0 (m_z \cos \theta_1 + m_y \sin \theta_1) Q}{(N_1 \cos \theta_0 + N_0 \cos \theta_1)(N_0 \cos \theta_0 + N_1 \cos \theta_1) \cos \theta_1} \quad (4)$$

$$r_{ss} = \frac{N_0 \cos \theta_0 - N_1 \cos \theta_1}{N_0 \cos \theta_0 + N_1 \cos \theta_1} \quad (5)$$

$$r_{ps} = \frac{jN_0 N_1 \cos \theta_0 (m_z \cos \theta_1 - m_y \sin \theta_1) Q}{(N_1 \cos \theta_0 + N_0 \cos \theta_1)(N_0 \cos \theta_0 + N_1 \cos \theta_1) \cos \theta_1} \quad (6)$$

where: θ_0 and θ_1 are the incidence angle and the refraction angle, respectively, N_0 and N_1 are the complex refractive index of non-magnetic incidence medium and magnetic medium, respectively, Q is the

magneto-optical constant, m_x , m_y , and m_z are the direction cosines of the magnetization vector.

3. Experimental details

The FeSiB amorphous thin films, with thickness between 120 nm – 250 nm, deposited onto glass substrate, were obtained by pulsed laser deposition [7, 9, 10]. The used target was a stack of several layers of Fe₇₉Si₉B₁₂ amorphous ribbons. The deposition was performed by means of a XeCl excimer laser, operating at 308 nm wavelength, with 30 ns pulse duration, 9 Hz repetition rate and 55 mJ pulse energy. Before starting the target ablation, the deposition chamber was evacuated to 10⁻⁶ Torr. The samples were investigated in as-deposited state.

The surface chemical composition of the obtained samples was studied by X-ray photoelectron spectroscopy (XPS). The amorphous state of the films was analyzed by X-ray diffractometry (XRD). The surface morphology was investigated by atomic force microscopy (AFM). The samples thickness was determined by interferometric method. The ellipsometric investigations were performed using an EL X-01R ellipsometer at 632.8 nm laser wavelength. For magneto-optical ellipsometry measurements, the ellipsometer was equipped with a pair of Helmholtz coils. Using the magneto-optical Kerr rotation dependence on external magnetic field intensity, the hysteresis loop was obtained, and the coercive force value was determined.

4. Results and discussion

The XPS investigation demonstrates that the composition of the deposited samples is very close to the target one, so that indicates target stoichiometry conservation.

The performed XRD measurements showed no crystalline peaks in the films diffraction spectra. This result confirms the expected amorphous phase formation in the deposited samples.

The AFM images showed that the surface roughness of the films is smaller than 35 nm.

Fig. 1 presents the dependence of the ellipsometric angles Ψ and Δ on the incidence angle for samples in the demagnetizing state. Using the principal angle ellipsometry method ($\Delta = \pi/2$), the equation (2) becomes [1]:

$$(n + jk)^2 = \sin^2 \theta_p [1 + tg^2 \theta_p (\cos 4\Psi_p + j \sin 4\Psi_p)] \quad (7)$$

where: θ_p is the principal incidence angle.

For the used wavelength, the values of n and k were found to be 2.3 and 1.75, respectively.

Using the n and k values, the reflectances R_p and R_s (the fraction of the total intensity of the incident plane wave that appears in the reflected wave) and reflection phase shifts δ_p and δ_s for p and s polarized light, respectively, were determined [1]. Figs. 2 and 3 present

the reflectance intensity and the phase shift dependence on the incidence angle for the p and s polarized light.

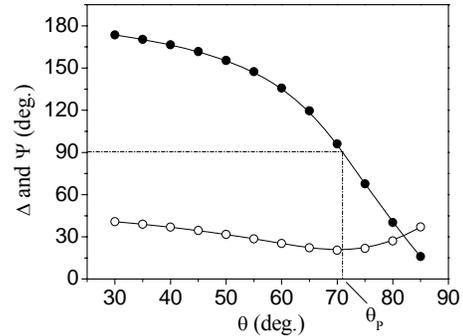


Fig. 1. Ellipsometric angles Ψ (\circ) and Δ (\bullet) as function of the incidence angle, θ , for FeSiB amorphous thin films.

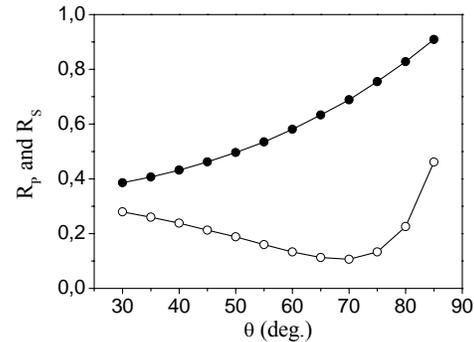


Fig. 2. The reflectances R_p (\circ) and R_s (\bullet) dependence on the incidence angle, θ , for FeSiB amorphous thin films.

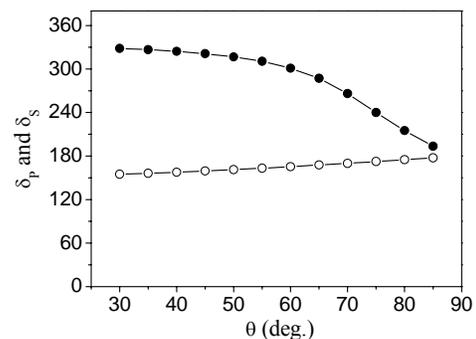


Fig. 3. The phase shifts δ_s (\circ) and δ_p (\bullet) dependence on the incidence angle, θ , for FeSiB amorphous thin films.

Using the magneto-optical measurements in the longitudinal Kerr configuration, the coercive force value was determined. For investigated samples with the thickness between 120 nm – 250 nm, the coercive force value was found to be in the range 980-995 A/m.

In the case of optically thick magnetic films, the complex Kerr rotation for the longitudinal configuration, $(\theta_K^p)^{long}$, can be expressed as [5]:

$$(\theta_K^p)^{long} = \left(\frac{r_{sp}}{r_{pp}} \right)^{long} = \frac{\cos \theta_0 \tan \theta_1}{\cos(\theta_0 + \theta_1)} \cdot \frac{jN_0 N_1 Q}{(N_1^2 - N_0^2)} \quad (8)$$

Fig. 4 presents the experimental and theoretical results concerning the dependence of $(\theta_K^p)^{long}$ on the incidence angle for a FeSiB sample, 120 nm thickness. The values of n and k are approximately equal with those obtained by ellipsometry. The experimental data were fitted by equation (8), using the least square method. The value of the magneto-optical constant was found to be $Q = 0.0177 - 0.0663j$.

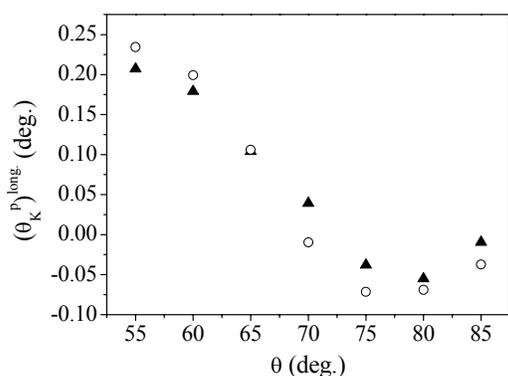


Fig. 4. Experimental (\blacktriangle) and theoretical (\circ) results concerning the dependence of $(\theta_K^p)^{long}$ on the incidence angle, θ , for FeSiB amorphous thin films.

5. Conclusions

FeSiB amorphous thin films deposited on glass substrate by pulsed laser deposition using as target $\text{Fe}_{79}\text{Si}_9\text{B}_{12}$ amorphous ribbons were investigated.

The value of the refractive index, extinction coefficient, magneto-optical constant and coercive force has been determined using the ellipsometry and magneto-optical Kerr effects. The measurements made at 632.8 nm wavelength give 2.3, 1.75 and 0.0177-0.0663j for n , k and Q , respectively. The coercive force value for the investigated samples was found to be in the range 980-995 A/m.

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